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Great Lakes Update

Geospatial Technologies for Great Lakes Water Management

The U.S. Army Corps of Engineers (USACE) serves an important role in Great Lakes water resources management. From monitoring water levels and shoreline changes to evaluating potential impacts on the environment, to assessing impacts of different regulation scenarios, the USACE participates in a wide variety of projects and studies using the latest in geospatial technologies.

Geospatial technologies refer to the tools that are used to acquire, analyze, store, and distribute data. The key, however, is that the data are referenced to their location by a real-world coordinate system. Geospatial technologies also include the sciences that study and analyze these data. Geospatial technologies are widely used to support research, monitoring, and water resources management efforts.

In the early part of the 20th century, the USACE did much of its work using hand drawn maps and hand calculated data. Surveys were conducted using lead lines and survey rods. The results were recorded on paper and later transferred to maps. Figure 1 shows a survey crew taking soundings in the Detroit River in 1939.

However, with the advent of new technologies such as computer-aided drafting and design tools, automated data collection, and remote sensing, these methods were changed drastically, reducing the time required and improving the quality of the data collected.

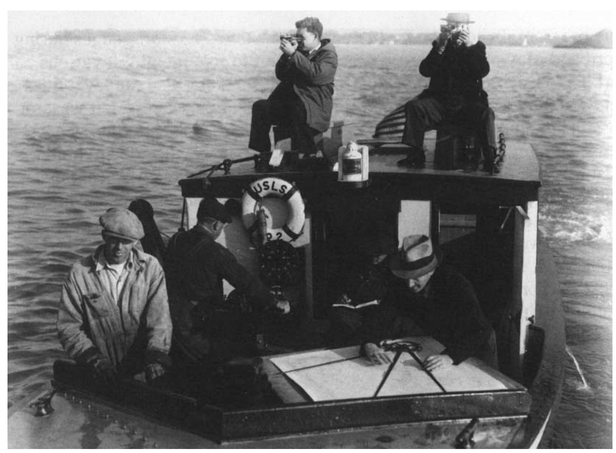

Figure 1. Taking soundings on board U.S. Lake Survey launch in the Detroit River, 1939

Today, we have progressed to a point where many surveys are taken from airplanes, changes along the shoreline can be assessed through aerial photos or satellite images, and computer models are being used to simulate the impacts and results of varying water level scenarios on the Great Lakes.

This update article focuses on some of the new geospatial technologies that are being used to help address Great Lakes water management issues and help support complex water resources studies. This article will address the uses of a variety of technologies including geographic information systems, remote sensing technologies, photogrammetry products, topographic and bathymetric data, and data access and management tools.

Geographic Information Systems

Geographical Information Systems (GIS) is a tool that unites data with its geographical reference to derive new information not present in the original dataset. For example, rainfall for a number of weather reporting stations can be mapped together with a lake's watershed boundary. Using GIS analysis tools, the total rainfall over the watershed can be determined.

GIS software has evolved to serve as a tool to capture, store, analyze, check, and display data and modeling scenarios in an endless number of ways. This helps immensely to visualize impacts, quickly calculate effects, and to display results.

For example, a map of a shoreline area can be overlaid with information on shore type, historical recession data, and proximity of houses and other structures. The GIS can then be used to calculate the number of miles of shoreline with a certain shore type, or assess how many structures are in danger of being damaged by future shoreline retreat. All this analysis is done in a geographical setting and allows for easy visualization and display of results.

GIS is also very useful in studying patterns or changes in land use, zoning, and other related characteristics. Land use types can be determined from photos. The GIS stores information about each zone of data, down to the individual building level. Layers of information can be overlaid to conduct land use change analysis or to discern development trends. By overlaying multiple layers, intersections of data can be calculated.

For example, by overlaying land use maps on top of a 100-year flood plain map, the type and area of different land uses susceptible to flooding can be calculated. Overlaying that same flood plain map on a highway map would allow you to calculate the number of miles of roadway that could be inundated in a 100-year flood. An example zoning GIS screen is shown in Figure 2.

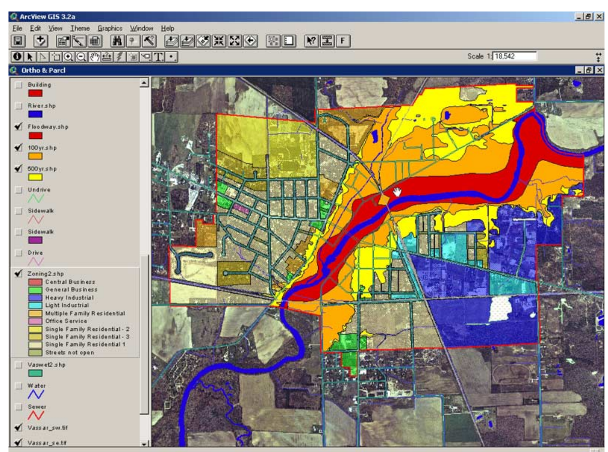

Figure 2. Flood plain and land use overlaid on digital orthophoto.

GIS is becoming more widely used across a wide variety of businesses. The USACE is converting much of its old survey data into digital format to be displayed in a GIS framework. Using this tool, bathymetric surveys of a harbor over several different time periods, for example, can be overlaid to calculate the amount of sediment deposition that occurred between each survey. This helps us determine the need for further dredging, to assess the impact of harbor structures, or to help in sediment budget analyses.

Another use of GIS at the USACE is in converting, cataloging, and making geographically based data available for analysis and evaluation. USACE is currently involved in the Lake Ontario - St. Lawrence River Study. This study is being directed by the International Joint Commission to review the regulation of outflows from Lake Ontario. A large amount of data is being collected to assist in the analysis of alternative regulation plans. Topographic and bathymetric data, aerial photographs, shoreline characteristics, environmental data, and recreational boating information are some of the data that are being collected to support the study.

An effort is underway to design a Great Lakes enterprise GIS, a data management tool that would warehouse all the data and support collaborative multi-agency/government work efforts. An enterprise GIS is a GIS that is set up so that it is accessible by many individuals simultaneously. This is the most important aspect of an enterprise GIS—that multiple users from different locations can access and work on the data. Other users can immediately see the changes and updated analyses on the datasets. This type of collaborative arrangement takes advantage of the skills and datasets of a variety of entities, thus maximizing the benefit to all.

The most important aspect of the enterprise GIS is that the data are available to be analyzed and queried. Thus, it is available to answer the questions of planners, engineers, and management to help them make informed decisions.

The data that are used in a GIS are collected in a variety of ways. The methods can include conventional surveys, gathering information from maps and databases, and collecting data using remote sensing techniques. The next section discusses several different methods of remote sensing data collection.

Remote Sensing Technologies

Remote sensing can be defined as the act of obtaining information by analyzing data collected by instruments that are not in contact with the object under investigation. It is, to put it simply, collection and analysis from a distance.

In contrast, *in situ* sensing involves physical contact with the object of measurement. While at first the differences between remote and *in situ* sensing may seem slight and their definitions intimidating, consider the following example. Our eyes act as remote sensors, constantly collecting and recording data about our surroundings by analyzing objects across the visible spectrum. Our hands can be considered *in situ* sensors, exploring and collecting information or data about objects by touching them.

Over the years, the USACE has embraced remote sensing as a means to collect and analyze data to support its water resources management mission. In many cases, new sensors have provided the USACE the ability to monitor phenomenon and environments that otherwise would have been inaccessible or immeasurable. In addition, by using remote sensing techniques, USACE has been able to repeatedly survey vast expanses at significant cost and timesavings when compared with *in situ* methods.

In the mid 1980s, the Detroit District began archiving satellite imagery from NOAA's

Advanced Very High Resolution Radiometer (AVHRR) sensor. This sensor provides imagery in the visible, near infrared, and thermal infrared wavelength bands, and can be used to monitor surface water temperature. Two NOAA satellites in orbit about 850 km above the Earth's surface collect the data. Together, the satellites provide nearly complete coverage of the Earth's surface twice a day.

In addition to archives of historic significance, this data could also be used to aid in calibration of future regulation models. Composite surface water temperature of the Great Lakes collected from AVHRR is produced daily by NOAA's Coast Watch program at http://superior.eng.ohio-state.edu/satelite/allakes/noframes/c.html. An example product from this website is shown in Figure 3.

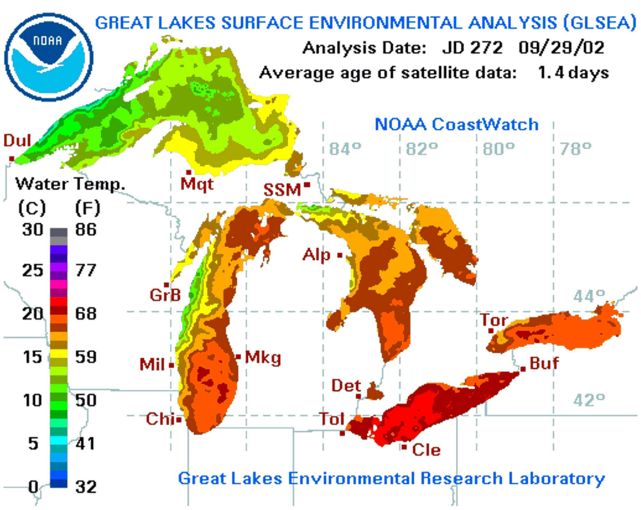

Figure 3. Example water temperature graphic showing surface water temperature of the Great Lakes (GLERL)

Another useful remote sensing data product is the collection of snow water equivalent data. USACE uses gamma surveys collected through the National Weather Service – National Operational Hydrologic Remote Sensing Center (NOHRSC) to evaluate the water content of the snowpack around the Lake Superior basin every March. The amount of water in the snowpack in early March is an important indicator of summer water levels in all of the Great Lakes. It is also important to forecasters who determine the potential severity of spring snowmelt runoff and flooding that would occur.

This technology was used to prepare for one of the worst floods ever experienced on the Red River of the North near Fargo, North Dakota in 1997. An example of a snow survey conducted in the upper Great Lakes basin in March 2002 is shown in Figure 4.

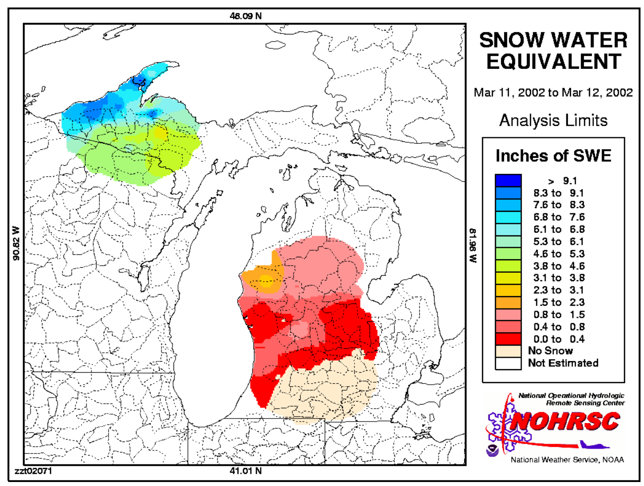

Figure 4. Snow Water Equivalent survey of the western Great Lakes region.

Another method of data collection using remote sensing is aerial photography. The next section gives some examples of how aerial photographs are used in Great Lakes water resources management.

Aerial Photography

Aerial photography and associated photo-grammetry products have long been used as a means of capturing important information about an area. In the Great Lakes region, aerial photography is used for many purposes, including monitoring of the coastline. Mapping of the Great Lakes' coastline using aerial photography dates back to the 1930s. Aerial photography became the primary mode of coastal mapping in the 1980s.

The USACE has been using and collecting aerial photography of specific coastal sites in the Great Lakes region dating as far back as 1938. Typical types of photography collected are panchromatic (black & white), natural color, and color infrared photography. The largest collection of hard copy photography that the USACE owns is a color infrared set collected from 1988 through 1993 of the entire U.S. shoreline of the Great Lakes. Copies of the above photo set were shared with state agencies to augment their own inventory of photos.

The USACE collects aerial photography for two main reasons--documenting geographic and demographic change over a specific site or developing photogrammetric products, often in support of larger projects. Aerial photography of the coastline is also very useful for a variety of coastal management studies, coastal change analysis, natural resource identification, and evaluation of development.

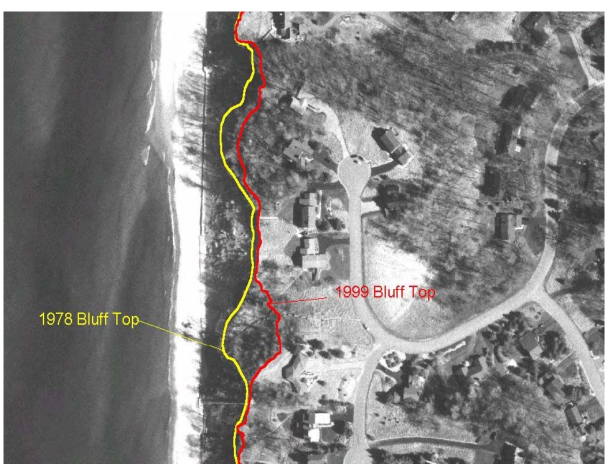

Figure 5. Digital aerial photo of Allegan County, Michigan showing 1978 and 1999 top of bluff.

Figure 5 shows an example of the use of current and historic aerial photography. The photo shows a coastal area on Lake Michigan. Using aerial photos from 1978 and 1999, the top of bluff was delineated. This can be used to determine the rate of bluff recession, or retreat. This information is invaluable to coastal managers who do research into bluff recession or who are responsible for establishing safe setbacks (the distance from the bluff top where development may occur).

Aerial photography that is collected for documenting geographic and demographic change is often flown uncontrolled (no geographic mapping control, meaning the photos are used for pictures with no precise geographic location or coordinates attached to them). This photography is used to monitor shoreline structures and shoreline protection, bluff lines, and shoreline demographics in forms of population growth and development trends.

In contrast, the photography that is collected for photogrammetric products requires mapping control survey. This photography is related to a specific project or studies that require photogrammetric mapping and/or digital orthophotography (DOP). These products allow the user to measure or identify specific items of interest on the photos. Typical studies would require measuring volume change in sand along the shoreline, developing baseline data for bluff recession and erosion studies, mapping harbors, and modeling high and low water scenarios along shorelines or in harbors.

To support specific projects, USACE will develop high-resolution digital data for a particular the study. For example, for the Lake Michigan Potential Damages Study, detailed orthophotos were collected in Allegan County, Michigan. The USACE flew aerial photography, collected mapping ground control, topographic elevation data, and developed very high-resolution digital orthophotography. With this high-resolution photography and associated data, top and toe of bluff, shore protection structures, shoreline property structures, and infrastructure can be mapped. In addition, projected bluff recession rates and future bluff positions based on modeling results were mapped on the aerial photos.

The collection of topographic data (discussed in detail in the next section) allowed a three dimensional image of the shoreline in the study area to be created, as shown in Figure 6. Figure 6 illustrates an effect called "draping," where the digital photo can be overlaid on a three-dimensional elevation model from the topographic data. The effect is a three-dimensional image of the area.

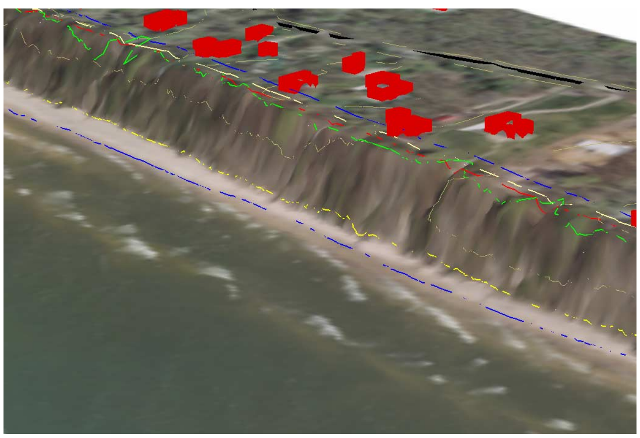

Figure 6 – An example showing planimetric mapping and digital orthophotography draped over an elevation model. (Note vertical scale exaggerated for visualization.)

The USACE uses many existing data sets in its management of the Great Lakes. Other datasets that are available include USGS Digital Orthophotography Quarter Quads (DOQQ) and USGS Digital Raster Graphs (DRG). DRGs are simply scans of the USGS topo quad maps that have historically been used only in paper copies. The DRGs are often used as a base map on projects where digital orthophotos are either not available or not desired to be used. Both DOQQs and DRGs are developed by the USGS and are used at the USACE on a daily basis for many different tasks.

As shown in the previous examples, the usefulness of digital orthophotography is greatly enhanced if detailed topographic data is also available. In the following section, new technologies for collecting topographic data are discussed.

Topographic Data

Historically, topographic data (the elevation of distinct points) was captured using hand surveys or by hand using stereo plotters (a process using pairs of aerial photos to develop elevations of particular points). These processes were very intense and time consuming. Once the data were developed, they were transferred to maps and contours were manually drawn. These techniques have been in use since the early explorers began keeping track of the places they had been. Extensive field surveys are necessary to do a complete job.

Manual cartography (making maps by hand) is still in use today, but the paper maps of old are rapidly being replaced by more automated procedures using computers to create digital maps. In addition, data collection techniques have changed dramatically.

Today a photogrammetrist or cartographer works at a computer and processes topographic data, establishing elevations for objects such as building outlines, streams, roads, bathymetric and topographic contours and other important features. All the features are based on data that were collected using remote sensing techniques. The elevation data are placed directly into a GIS database or digital map. Field surveys are still being used to validate these digital data sets, but they tend to be less extensive than those used for manual mapping.

With the development of new automated technologies, such as Light Detecting And Range (LIDAR) collection techniques for collecting topographic and bathymetric data, the creation of topographic data has become more affordable. LIDAR is collected using airborne global positioning system (GPS) and lasers (Figure 7) from what is known as an active platform. The active platforms could be an airplane or helicopter.

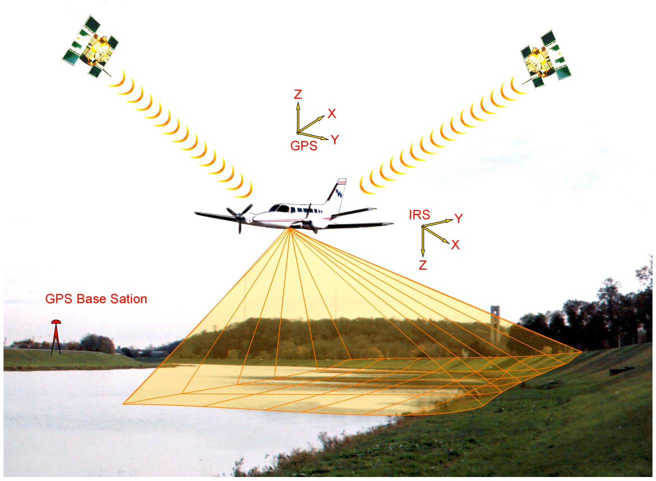

Figure 7. LIDAR Acquisition (Woolpert Design, LLP)

Using this new technology greatly reduces the time it takes to prepare topographic and bathymetric data, thus reducing the cost of data development significantly. Topographic and bathymetric data collected in this manner will continue to become more affordable over time as the technology comes into more use.

The USACE uses topographic and bathymetric data collected with LIDAR technology in conjunction with other data sets (remote sensing and geographic information) in a geographic information system within the Great Lakes watershed. These GIS datasets support hydraulic and hydrological modeling, monitoring of water level changes, flood elevation modeling, coastal sand management, potential shoreline damage studies, the tracking and monitoring of changes in shoreline location, and the impacts of an increasing or receding shoreline.

The use of topographic and bathymetric elevation data is becoming fundamental for the USACE to complete its mission. LIDAR collection provides a cost-effective means to collecting large areas of topographic and bathymetric elevation data.

Figure 8 shows an example of how these datasets collected using remote sensing come together for analysis. Figure 8 shows a digital orthophoto, with bathymetric and topographic contours, together with the current bluff and a projected future bluff.

Figure 8. Digital orthophotography shown with contours and projected bluff lines. Allegan County, Michigan

Bathymetric and topographic LIDAR data have also been collected to support the Lake Ontario-

St. Lawrence River Study. Figure 9 shows the creation of a triangulated irregular network (TIN) and contours after the merging of topographic and bathymetric LIDAR data along the southern shore of Lake Ontario. This particular dataset will be very useful in projecting the impacts of water level changes, using the various contours to identify where the water's edge would be under different water level conditions.

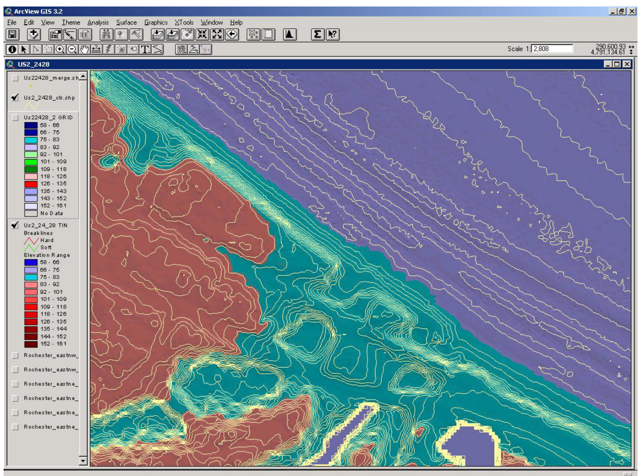

Figure 9 – TIN overlaid with contours

This data can be manipulated in the digital environment to create an array of maps and views of the project site and to obtain precise measurements of structures, contours, and other vital information

Summary

Technology has progressed from simple paper maps based on field measurements to very sophisticated models built from remote sensing data and input. New technologies are giving scientists that work on the Great Lakes and, in turn the general public, a wealth of information about the environment and how it is constantly changing. This allows water resources managers to make more timely and better-informed decisions.

These new technologies also allow more data to be collected in a more cost-effective manner. As with all technological advances in the 21st century, geospatial data will continue to increase in volume and sophistication, providing new and exciting opportunities for Great Lakes water managers, decision makers, and the public alike.

For example, satellites have traditionally provided imagery at a lesser resolution than aerial photography. However, as the capabilities of sensors continue to evolve and new technologies come on line, the spatial resolution of future satellite systems and imagery will likely rival that of traditional aerial photography. This will provide repeatable, dependable coverage of vast areas like the Great Lakes basin in a timely, cost-effective manner. In turn, this will allow us to view our world in ways that we could have only imagined a few short years ago.

By combining new geospatial technologies with traditional expertise and methodologies, the USACE will be ready to meet future challenges and continue to excel in its role as a Great Lakes water resources manager. For as technology advances, so too do the knowledge bases and applications for resource management in the Great Lakes.